How does postural stability following a single leg drop jump landing task relate to postural stability during a single leg stance balance task?

Fransz, D.P.; Kingma, I.; Huurnink, A.; van Dieen, J.H.

published in
Journal of Biomechanics
2014

DOI (link to publisher)
10.1016/j.jbiomech.2014.06.019

ARTICLE IN PRESS

Journal of Biomechanics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

How does postural stability following a single leg drop jump landing task relate to postural stability during a single leg stance balance task?

Duncan P. Fransz [a,*], Arnold Huurnink [a,b], Idsart Kingma [a], Jaap H. van Dieën [a,c]

[a] Research Institute MOVE Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, Amsterdam, The Netherlands
[b] Department of Nuclear Medicine, Academic Medical Center, Amsterdam, The Netherlands
[c] King Abdulaziz University, Jeddah, Saudi Arabia

ARTICLE INFO

Article history:
Accepted 11 June 2014

Keywords:
Force platform
Postural control
Dynamic test
Center of pressure
Ground reaction forces

ABSTRACT

We aimed to verify whether the static phase after a single leg drop jump (DJ) landing on a force plate may serve as a proxy for a single leg stance (SLS) balance task, as this would increase the application possibilities of landing tasks in the evaluation of sensorimotor function in relation to injury rehabilitation or performance assessment.

Twenty-five healthy participants performed two sessions of five valid trials for both tasks in a reproducibility-agreement design. Three postural stability outcome measures ('COP speed', 'COP sway' and 'Horizontal GRF') were calculated for DJ (5–20 s after landing) and for SLS (15 s), and were averaged per session. Paired *T*-tests revealed a learning effect of SLS for postural stability (4.6–6.1%; *P*-values <0.03), in contrast to DJ (*P*-values >0.27). Only session 2 resulted in superior postural stability for SLS compared to DJ for 'COP speed' (5.0%; $P=0.017$) and 'Horizontal GRF' (8.2%; $P=0.001$). Bland and Altman methods demonstrated inter-session SD's of difference for DJ of 11–12% and for SLS of 10–12%, while inter-task SD's of difference ranged 10–17%. Precision ('SD within') was better for SLS concerning 'COP speed' (14–15% vs 13%) and 'Horizontal GRF' (18–20% vs 14–15%). In conclusion, postural stability during DJ and SLS cannot be considered interchangeable, due to a learning effect for SLS and inferior precision for DJ. However, a DJ task may be used as a proxy for static postural stability, although more than three trials are needed to achieve individual errors similar to SLS for 'COP speed' (4) and 'Horizontal GRF' (5).

1. Introduction

Testing of single leg balance has an important place in the evaluation of athletic performance (Hrysomallis, 2011) and the assessment of injuries such as ankle sprains (Ross et al., 2009; Witchalls et al., 2013) or untreated anterior cruciate ligament deficiency (Negahban et al., 2013). Single leg postural stability is considered to reflect total body sensorimotor function (Witchalls et al., 2013). However, it has been suggested that demanding tasks, such as a hop landing, may be a better representation of sensorimotor functioning (Hupperets et al., 2009). Therefore, an increasing number of studies focus on these dynamic tasks (Fransz et al., 2013). Both static and dynamic postural stability are often assessed with a force plate, and quantified by outcome measures derived from the center of pressure (COP) or ground reaction force (GRF).

The employment of both dynamic and static tests in a single measurement protocol requires a large amount of time or could lead to an increased burden for researchers and participants, especially in large-scale assessments that take place on a regular basis. The most commonly used dynamic task consists of a single leg landing event, followed by the transition to static balance (Fransz et al., 2013). As a result, it might be possible to calculate outcome measures such as peak forces, dynamic stability and static stability from the same test, encompassing different aspects of sensorimotor functioning. This would increase measurement efficiency substantially.

Therefore, the aim of the present study was to verify whether it is possible to assess postural stability during the static phase after a single leg drop jump landing as a proxy for static postural stability during a static single leg stance.

2. Methods

2.1. Participants

A convenience sample consisting of 25 physically active volunteers was recruited (20 men, 5 women; mean (range); age 28.6 (20–53) years; height 183.3

* Correspondence to: Research Institute MOVE Amsterdam, Faculty of Human Movement Sciences, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands. Tel.: +3120 5988492;
fax: +3120 5988529.
E-mail address: dpfransz@gmail.com (D.P. Fransz).

http://dx.doi.org/10.1016/j.jbiomech.2014.06.019
0021-9290/© 2014 Elsevier Ltd. All rights reserved.

(163–197) cm; body weight 76.9 (59–96) kg). None of the participants reported any neuromusculoskeletal injuries or other diseases likely to affect balance performance. Written informed consent was obtained once the purpose, nature and potential risks had been explained. The study was performed according to the Declaration of Helsinki and approved by the Human Ethics Committee of the Faculty of Human Movement Sciences of the VU University in Amsterdam.

2.2. Procedures

We chose to employ a reproducibility-agreement design to compare the static phase of a single leg 'drop jump' landing (DJ) with a static 'single leg stance' (SLS) task. Therefore, we asked each participant to perform two sessions of five valid trials for both tasks. The DJ was executed from a 30 cm high box, which was placed 5 cm posterior to the force plate. Participants stood on the testing leg, took off, landed on the same leg, stabilized as quickly as possible and balanced for 20 s as motionless as possible. Other than 'hop off the box', no instructions (with regard to jump height) were given. With regard to the SLS, the participants were instructed to stand on the testing leg for 15 s as motionless as possible. The measurement started when participants indicated that they had achieved a comfortable and stable single leg stance. Both tasks were performed barefooted and with both hands on the hips.

The DJ and SLS were performed in alternating order, while the starting task was counterbalanced across participants. Participants were given 30 s of rest between trials and 5 min of rest between sessions. A trial was considered invalid if a participant displaced his/her standing leg, touched the floor with the contralateral leg or if arm movement was used to regain balance. Participants chose the testing leg by identifying their leg of preference after two DJ practice trials; this was not expected to bias results (Huurnink et al., 2014a).

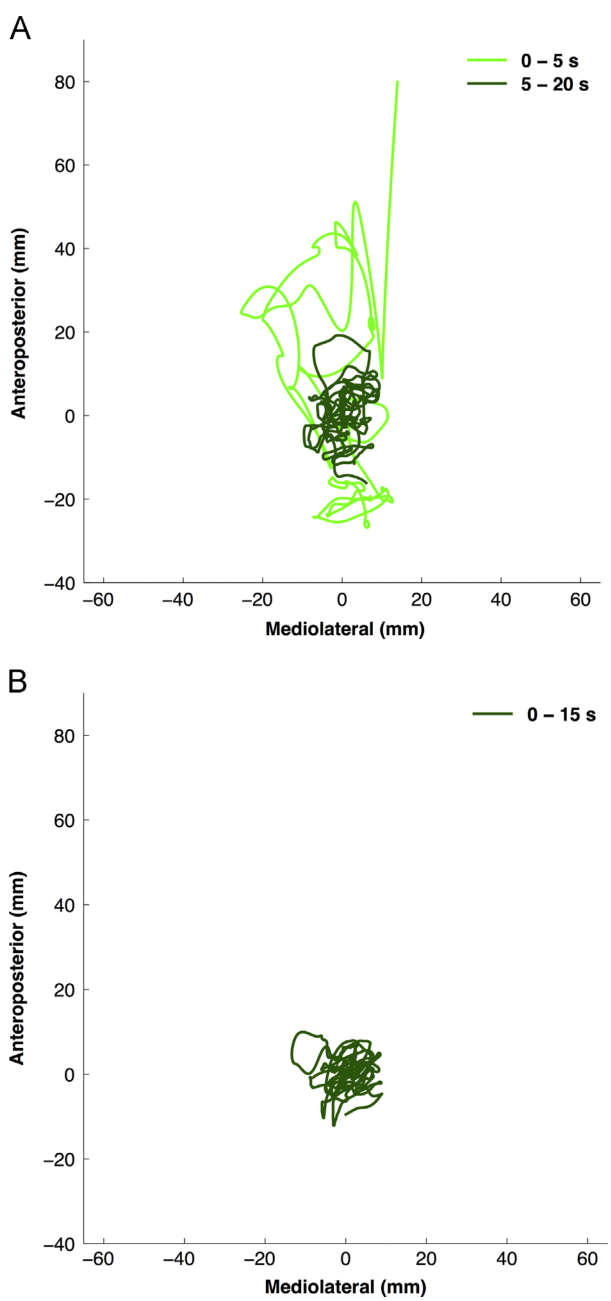

Fig. 1. Typical COP trajectories during single leg drop jump landing task (A) and during a single leg stance balance task (B).

2.3. Data processing

Ground reaction forces were sampled at 1000 samples/s by a 60 by 40 cm force plate (type 9218B, Kistler Instrument Corp, Winterthur, Switzerland), which was mounted flush with the laboratory floor. A custom MATLAB (The Mathworks, Natick, RI, USA) program was written for data reduction. Raw data was low pass filtered at 12 Hz with a bidirectional second order Butterworth filter (Huurnink et al., 2013). The COP calculations were based on vertical and horizontal forces in accordance with the manufacturer's manual. With regard to the DJ data, the data was cropped from impact (>10 N) to 20 s post-impact. The start of the static phase of the DJ was set at 5 s post-impact, based on previous 'time to stabilization' outcome values (Colby et al., 1999; DiStefano et al., 2010; Wikstrom et al., 2005).

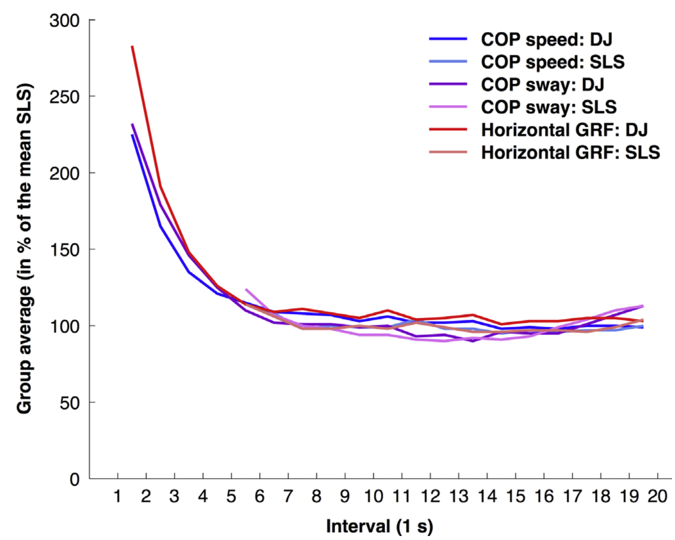

Fig. 2. The group average of the means for the outcomes measures 'COP speed', 'COP sway' and 'Horizontal GRF', as calculated during 1 s intervals for both DJ and SLS. The value for the mean SLS over 15 s was set at 100%. Each interval covers 1 s (e.g. 1–2 s, 2–3 s, 3–4 s, etc.). To achieve easier assessment, the SLS data (0–15 s) were plotted in the relevant time period with regard to the DJ (5–20 s).

Table 1
Static postural stability calculated from DJ and SLS tasks.

Outcome measure	Task	Mean	SD within (%)	SD between (%)
COP speed (in mm/s)	DJ1	48.40	6.81 (14%)	11.6 (24%)
	DJ2	47.25	7.14 (15%)	13.7 (29%)
	SLS1	47.74	6.01 (13%)	12.2 (26%)
	SLS2	44.97	5.92 (13%)	12.6 (28%)
COP sway (in mm)	DJ1	8.99	1.31 (15%)	1.78 (20%)
	DJ2	8.90	1.43 (16%)	1.75 (20%)
	SLS1	9.16	1.39 (15%)	1.68 (18%)
	SLS2	8.75	1.39 (16%)	1.73 (20%)
Horizontal GRF (in N)	DJ1	3.87	0.70 (18%)	1.12 (29%)
	DJ2	3.80	0.77 (20%)	1.32 (35%)
	SLS1	3.72	0.54 (14%)	1.06 (29%)
	SLS2	3.50	0.53 (15%)	1.12 (32%)

DJ1 consists of trials 1–5 for the DJ task; DJ2 trials 6–10; SLS1 trials 1–5 for the SLS task; and SLS2 trials 6–10. The 'Mean' is the average over 250 (25 subjects × 5 trials) values; 'SD within' is the SD over 5 trials per subject, averaged across 25 subjects; 'SD between' is the SD between participants, based on the mean value per individual (average of 5 trials); relative values (%) concern the percentage of the mean value of the corresponding task.

Postural stability was assessed through three reliable and discriminative outcome measures for DJ (5–20 s after landing) and for SLS (15 s):

(1) The mean COP speed (‘*COP speed*’), which is the total COP path length divided by trial time (Doyle et al., 2007; Huurnink et al., 2014b; Kiers et al., 2012; Paillard et al., 2006; Salavati et al., 2009).
(2) The mean COP sway (‘*COP sway*’), which is the mean absolute distance of the COP trajectory to the average COP position (Clark et al., 2010; Jakobsen et al., 2011).
(3) The mean absolute horizontal GRF (‘*Horizontal GRF*’), which is the mean length of the GRF vector in the horizontal plane (Huurnink et al., 2014b; Ross et al., 2009).

Table 2
The reproducibility and agreement comparisons.

Outcome measure	Comparison	Mean diff (%)	95% CI in %	*P*-value	SD diff (%)	95% LOA	ICC (95% CI)
Reproducibility							
COP speed (in mm/s)	DJ1 vs DJ2	1.15 (2.4%)	(−2.1–6.9)	0.282	5.22 (11%)	[−9.07–11.4]	0.92 (0.82–0.96)
	SLS1 vs SLS2	2.78 (6.0%)	(1.6–10.4)	0.009	4.90 (11%)	[−6.83–12.3]	0.90 (0.74–0.96)
COP sway (in mm)	DJ1 vs DJ2	0.09 (1.0%)	(−3.4–5.5)	0.634	0.96 (11%)	[−1.79–1.97]	0.86 (0.70–0.93)
	SLS1 vs SLS2	0.41 (4.6%)	(0.6–8.6)	0.028	0.88 (10%)	[−1.32–2.14]	0.85 (0.66–0.93)
Horizontal GRF (in N)	DJ1 vs DJ2	0.07 (1.9%)	(−2.9–6.8)	0.430	0.46 (12%)	[−0.82–0.97]	0.93 (0.85–0.97)
	SLS1 vs SLS2	0.22 (6.1%)	(1.4–10.8)	0.013	0.41 (11%)	[−0.59–1.03]	0.91 (0.77–0.96)
Agreement							
COP speed (in mm/s)	DJ1 vs SLS1	0.66 (1.4%)	(−2.8–5.6)	0.510	4.88 (10%)	[−8.91–10.2]	0.92 (0.82–0.96)
	DJ2 vs SLS2	2.29 (5.0%)	(1.0–8.9)	0.017	4.45 (10%)	[−6.44–11.0]	0.93 (0.82–0.97)
COP sway (in mm)	DJ1 vs SLS1	−0.17 (−1.9%)	(−7.4–3.6)	0.482	1.21 (13%)	[−2.54–2.20]	0.76 (0.53–0.89)
	DJ2 vs SLS2	0.15 (1.7%)	(−2.6–6.0)	0.434	0.92 (11%)	[−1.66–1.96]	0.86 (0.71–0.94)
Horizontal GRF (in N)	DJ1 vs SLS1	0.15 (4.0%)	(−2.9–10.8)	0.240	0.63 (17%)	[−1.08–1.38]	0.83 (0.66–0.92)
	DJ2 vs SLS2	0.30 (8.2%)	(3.6–12.9)	0.001	0.41 (11%)	[−0.50–1.10]	0.92 (0.71–0.97)

The ‘mean differences’, ‘95% confidence interval (CI) and ‘SD of difference’ are calculated from the mean value per subject (5 trials); relative values (%) concern the percentage of the mean value with regard to that comparison; *P*-values are calculated with two-way paired Student *T*-tests; the ‘95% LOA’ are the 95% limits of agreement (‘Mean diff’ − 1.96 * ‘SD diff’ to ‘Mean diff’ + 1.96 * ‘SD diff’); the intraclass correlation coefficient (ICC) is a two way random single measures for consistency/absolute agreement (ICC2,1), with the 95% CI.

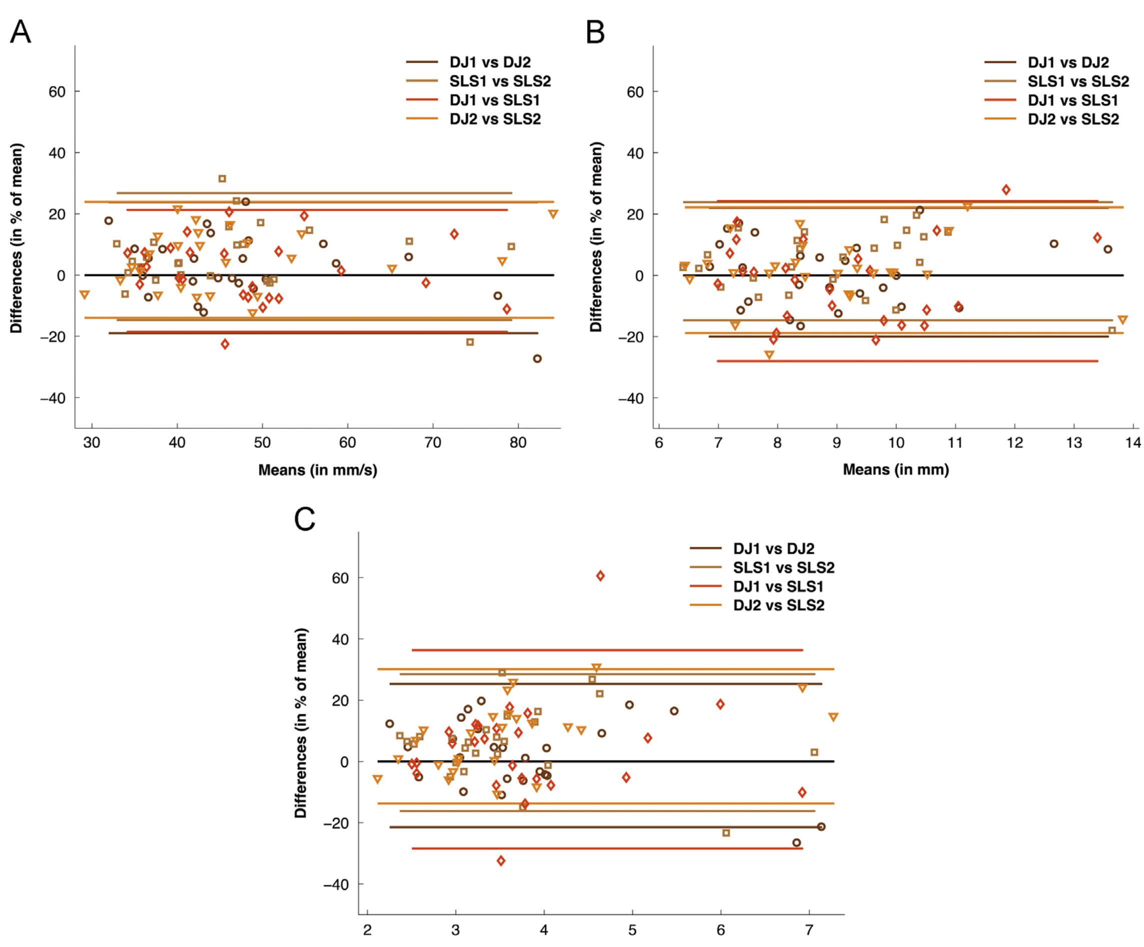

Fig. 3. Bland–Altman plots for both reproducibility and agreement comparisons, for ‘COP speed’ (A), ‘COP sway’ (B) and ‘Horizontal GRF’ (C).

Furthermore, to illustrate the effect of time after landing, the values of each trial were also calculated per 1 s interval for the DJ and SLS data sets and averaged across all trials.

2.4. Statistical analysis

Statistical analysis was performed using the Statistical Program for Social Sciences (version 21.0, SPSS Inc., Chicago, IL, USA). The precision of each outcome value was estimated with the 'SD within' and the variance between participants with the 'SD between'. To assess the reproducibility and agreement of postural stability outcome measures calculated from DJ and SLS tasks, the Bland and Altman (1986, 2003) method was employed. Therefore, mean difference, SD of difference and 95% limits of agreement (LOA) were calculated for inter-session comparisons (SLS1 vs SLS2; DJ1 vs DJ2) and inter-task comparisons (DJ1 vs SLS1; DJ2 vs SLS2). The two-way paired Student *T*-test was employed to test for differences between sessions 1 and 2, and between DJ and SLS, for all outcome measures. Statistical significance was set at $P<0.05$. The intraclass correlation coefficient between the comparisons was calculated after averaging over five trials (ICC(2,1); two-way random single measures for absolute agreement).

To assess the effect of number of trials on the standard error of the mean individual outcome (to be denoted as the 'individual error': 'SD within'/$\sqrt{n}$ trials), the 'SD within' was also calculated for all possible number of trials per participant (2–10).

3. Results

Typical examples of COP trajectories (Fig. 1) provide visual support (post-hoc) that after 5 s following the initial contact in the DJ, figures for DJ and SLS are comparable. This suggests that after 5 s, the participants had reached a stable position, which was confirmed by averaged outcomes over time (Fig. 2) and was also supported by the absence of a significant difference between DJ and SLS for all outcome measures in the first session (see below). The mean number of invalid trials for the DJ was 1.44 (SD=1.78) for the first session and 2.40 (SD=3.16) for the second session, while this was negligible for the SLS task.

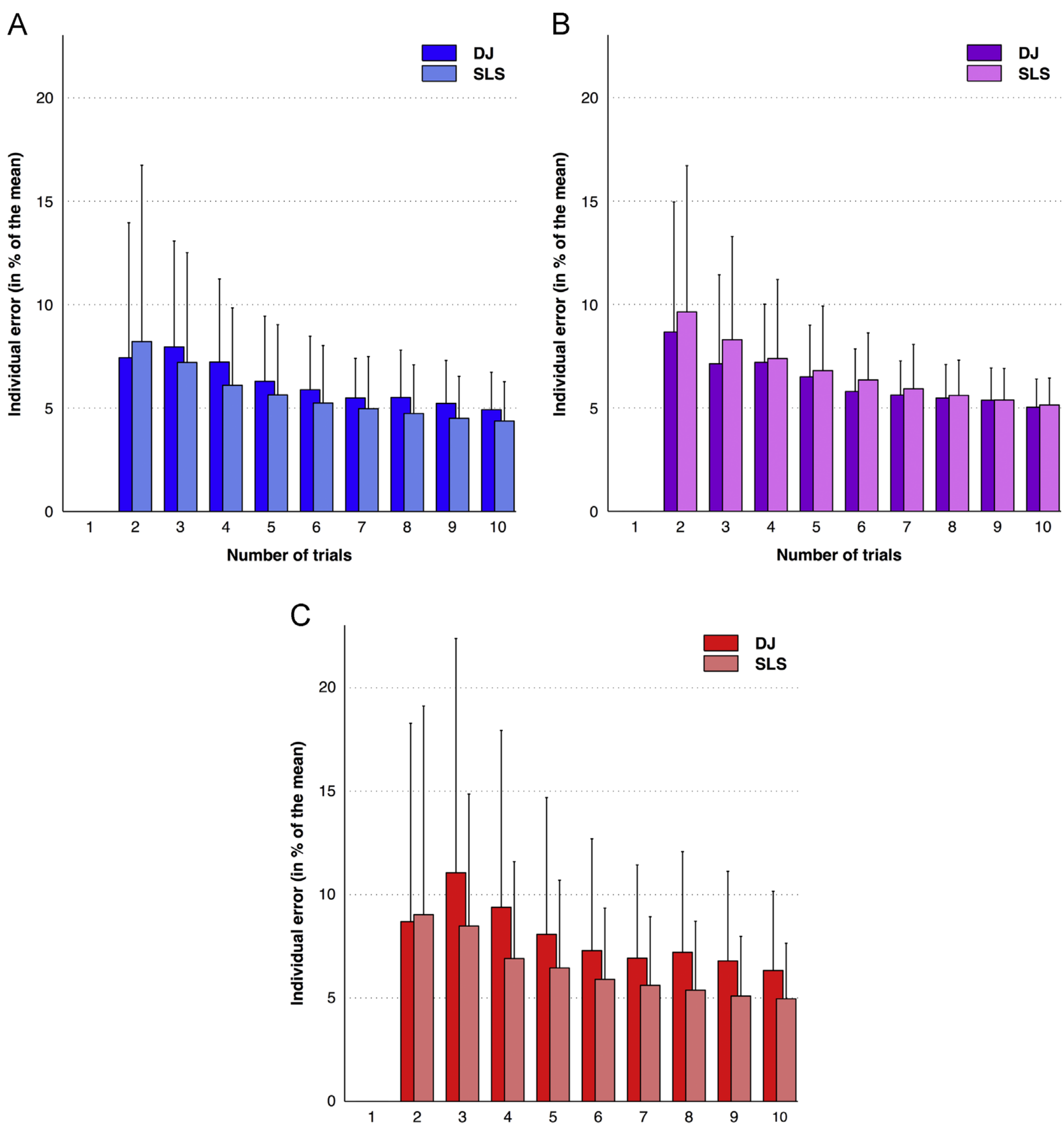

Fig. 4. The individual error ('SD within'/$\sqrt{n}$ trials) presented as mean and SD across 25 participants for 'COP speed' (A), 'COP sway' (B) and 'Horizontal GRF' (C) for both DJ and SLS, as calculated based on a varying number of trials (2–10 trials). Values are relative to the associated mean outcome value, based on the same number of trials.

Table 1 shows that variance between participants ('SD between') was comparable for DJ and SLS, while 'SD within' (precision) was smaller for the SLS task with regard to 'COP speed' (13% vs 14–15%) and 'Horizontal GRF' (14–15% vs 18–20%). However, this was hardly demonstrated by the reproducibility analyses, as the SD of differences (% of mean) between sessions 1 and 2 for DJ and SLS were comparable (11–12% vs 10–11%, respectively) (see Table 2).

The postural stability calculated from SLS was significantly better during session 2 compared to session 1, with lower values for all three outcome measures (P-values <0.029). This may indicate a learning effect for SLS, while this was not the case for DJ task (P-values >0.281) (see Table 2). When comparing DJ and SLS for session 1, no systematic differences were apparent (P-values >0.239). However, session 2 did reveal a systematic difference between both tasks with significantly lower values for 'COP speed' ($P=0.017$) and 'Horizontal GRF' ($P=0.001$) for SLS.

Bland and Altman plots are presented in Fig. 3, illustrating comparable variance of error among the comparisons regarding reproducibility and agreement between DJ and SLS. Nevertheless, the range of the SD's of difference (and consequently the 95% LOA) was larger for DJ vs SLS comparisons (10–17% of the mean) than for reproducibility comparisons (10–12%) (see Table 2).

Finally, as the individual outcome is usually an average across a number of trials, Fig. 4 illustrates the 'individual error' of outcome values, related to the number of trials. The individual error of the 'Horizontal GRF', and to a lesser extent 'COP speed', was larger and more variable over subjects for DJ compared to SLS.

4. Discussion

The main finding of the current study is that postural stability calculated from 5 s to 20 s following a single leg drop jump landing cannot be considered interchangeable with postural stability calculated from a single leg stance balance task of 15 s. This difference appears to be caused by a lower precision of the 'COP speed' and 'Horizontal GRF' outcome measures for the DJ task, and by a learning effect for SLS task, which was absent for the DJ task.

Although the cause of the observed lack of precision of the 'COP speed' and 'Horizontal GRF' for DJ may not be modifiable, it is possible to decrease the variance of the individual outcome by increasing the number of trials (see Fig. 4). Most studies on static postural stability use a mean of three SLS trials to calculate an outcome value. To achieve a similar error of the mean (for an individual outcome), it seems that four ('COP speed'), three ('COP sway') or five trials ('Horizontal GRF') of the DJ task are sufficient (see Fig. 4).

A possible explanation for the absence of a learning effect regarding postural stability in the DJ tasks between sessions 1 and 2, could be the detrimental effect of fatigue or a lack of concentration. Although participants were granted rest between trials and between sessions, the increased mean number of invalid trials for session 2 compared to session 1, might suggest the onset of fatigue or lack of concentration. Nevertheless, the absence of a systematic difference of postural stability between sessions 1 and 2 suggests that, in contrast to SLS, it is 'safe' to further increase the number of trials.

The 95% LOA's between DJ and SLS were substantial, but they also included intra-subject variability. As the 95% LOA of the comparisons of reproducibility were largely similar to the comparisons of agreement, the high 95% LOA between DJ and SLS could be mainly attributed to intra-subject variability. If postural stability is employed to compare group means, the standard error of the mean would be substantially smaller (as they are to be divided by $\sqrt{n}$ participants).

With regard to the generalizability of our findings, it should be noted that the participants of the current study were all healthy, physically active individuals. The employed DJ task might prove to be too demanding for some individuals, for instance patients in the (sub-) acute phase after injury. Moreover, injuries may result in longer time to stabilization. Therefore, depending on the population, the analysis of a later time window (e.g. 10–25 s) deserves consideration. Furthermore, we are unsure if the current results are generalizable to other landing protocols that employ different procedures, such as other jump/hop directions or a starting position on two legs or the non-testing leg. It can be expected that easier protocols would lead to smaller increases of variance of postural stability outcomes, while more difficult protocols would lead to a larger increase.

In conclusion, postural stability during the 5–20 s following a drop jump landing cannot be considered interchangeable with a single leg stance task of 15 s. However, the present data support the notion that a DJ task may be used as a proxy for static postural stability, although more trials may be needed to achieve individual errors similar to SLS for 'COP speed' and 'Horizontal GRF'. The additional value of the incorporation of static postural stability into the DJ test needs to be determined, but it may well improve the application for testing sensorimotor function. This single test protocol could enhance large-scale measurement programs, such as the periodic testing programs in (professional) sport clubs, schools and sports medicine, by providing information on both the dynamic aspect (e.g. landing forces, time to stabilization) and the static aspect (postural stability) of sensorimotor functioning.

Conflict of interest statement

There is no conflict of interest.

Acknowledgments

We would like to thank Matthew B.A. Harmon, MD, for his contributions to the manuscript.

References

Bland, J.M., Altman, D.G., 1986. Statistical methods for assessing agreement between two methods of clinical assessment. Lancet 327, 307–310.
Bland, J.M., Altman, D.G., 2003. Applying the right statistics: analyses of measurement studies. Ultrasound Obstet. Gynecol. 22, 85–93.
Clark, R.A., Bryant, A.L., Pua, Y., McCrory, P., Bennell, K., Hunt, M., 2010. Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. Gait Posture 31, 307–310.
Colby, S.M., Hintermeister, R.A., Torry, M.R., Steadman, J.R., 1999. Lower limb stability with ACL impairment. J. Orthop. Sports Phys. Ther. 29, 444–451 (discussion 452-444).
DiStefano, L.J., Padua, D.A., Blackburn, J.T., Garrett, W.E., Guskiewicz, K.M., Marshall, S.W., 2010. Integrated injury prevention program improves balance and vertical jump height in children. J. Strength Cond. Res. 24, 332–342.
Doyle, R.J., Hsiao-Wecksler, E.T., Ragan, B.G., Rosengren, K.S., 2007. Generalizability of center of pressure measures of quiet standing. Gait Posture 25, 166–171.
Fransz, D.P., Huurnink, A., Kingma, I., Verhagen, E.A.L.M., van Dieën, J.H., 2013. A systematic review and meta-analysis of dynamic tests and related force plate parameters used to evaluate neuromusculoskeletal function in foot and ankle pathology. Clin. Biomech. (Bristol, Avon) 28, 591–601.
Hrysomallis, C., 2011. Balance ability and athletic performance. Sports Med. 41, 221–232.
Hupperets, M.D.W., Verhagen, E.A.L.M., van Mechelen, W., 2009. Effect of sensorimotor training on morphological, neurophysiological and functional characteristics of the ankle: a critical review. Sports Med. 39, 591–605.
Huurnink, A., Fransz, D.P., Kingma, I., van Dieën, J.H., 2013. Comparison of a laboratory grade force platform with a Nintendo Wii Balance Board on measurement of postural control in single-leg stance balance tasks. J. Biomech. 46, 1392–1395.
Huurnink, A., Fransz, D.P., Kingma, I., Hupperets, M.D.W., van Dieën, J.H., 2014a. The effect of leg preference on postural stability in healthy athletes. J. Biomech. 47, 308–312.

Huurnink, A., Fransz, D.P., Kingma, I., Verhagen, E.A.L.M., van Dieën, J.H., 2014b. Postural stability and ankle sprain history in athletes compared to uninjured controls. Clin. Biomech. (Bristol, Avon) 29, 183–188.

Jakobsen, M.D., Sundstrup, E., Krustrup, P., Aagaard, P., 2011. The effect of recreational soccer training and running on postural balance in untrained men. Eur. J. Appl. Physiol. 111, 521–530.

Kiers, H., Brumagne, S., van Dieën, J.H., van der Wees, P., Vanhees, L., 2012. Ankle proprioception is not targeted by exercises on an unstable surface. Eur. J. Appl. Physiol. 112, 1577–1585.

Negahban, H., Mazaheri, M., Kingma, I., van Dieen, J.H., 2013. A systematic review of postural control during single-leg stance in patients with untreated anterior cruciate ligament injury. Knee Surg. Sports Traumatol. Arthrosc.

Paillard, T., Noé, F., Rivière, T., Marion, V., Montoya, R., Dupui, P., 2006. Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. J. Athl. Train. 41, 172–176.

Ross, S.E., Guskiewicz, K.M., Gross, M.T., Yu, B., 2009. Balance measures for discriminating between functionally unstable and stable ankles. Med. Sci. Sports Exerc. 41, 399–407.

Salavati, M., Hadian, M.R., Mazaheri, M., Negahban, H., Ebrahimi, I., Talebian, S., Jafari, A.H., Sanjari, M.A., Sohani, S.M., Parnianpour, M., 2009. Test–retest reliability of center of pressure measures of postural stability during quiet standing in a group with musculoskeletal disorders consisting of low back pain, anterior cruciate ligament injury and functional ankle instability. Gait Posture 29, 460–464.

Wikstrom, E.A., Tillman, M.D., Borsa, P.A., 2005. Detection of dynamic stability deficits in subjects with functional ankle instability. Med. Sci. Sports Exerc. 37, 169–175.

Witchalls, J.B., Newman, P., Waddington, G., Adams, R., Blanch, P., 2013. Functional performance deficits associated with ligamentous instability at the ankle. J. Sci. Med. Sport 16, 89–93.

Please cite this article as: Fransz, D.P., et al., How does postural stability following a single leg drop jump landing task relate to postural stability during a single leg stance balance task?. Journal of Biomechanics (2014), http://dx.doi.org/10.1016/j.jbiomech.2014.06.019